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(71) Applicant(s)
Ando Electric Co Ltd

(Incorporated in Japan)

19-7 Kamata 4-chome, Ota-ku, Tokyo, Japan

(72) Inventor(s)
Shinya Nagashima

(74) Agent and/or Address for Service
Hepworth Lawrence Bryer & Bizley
Bloxam Court, Corporation Street, RUGBY, CV21 2DU, United Kingdom

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GB 1195839 A EP 0478785 A1 EP 0436752 A1
EP 0332699 A1 EP 0256300 A2 US 4426155 A
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(58) Field of Search
UK CL (Edition M) G1A AHSL AHX
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Online databases: WPI, EDOC

(54) Optical wavemeter

(57) In an optical wavemeter light 26 of unknown wavelength is divided into first and second beams by a beam splitter. The first beam is reflected by a fixed mirror 21 back into the beam splitter, and is then received by a light receiver 24. The second beam is reflected by a moving mirror 22 back into the beam splitter, and is then received by the light receiver 24. The first and second beams interfere with each other in the light receiver. When a stage 28 carrying mirror 22 moves, the receiver signal S_3 varies in response to the periodic variation of the intensity of the interference light. A length measuring device comprising crossed gratings 32, 33 detects the moving distance of the stage 28. A wavelength calculator 27 calculates the wavelength of the light to be measured based on the wavenumber of the receiver signal and the moving distance.

FIG. 1

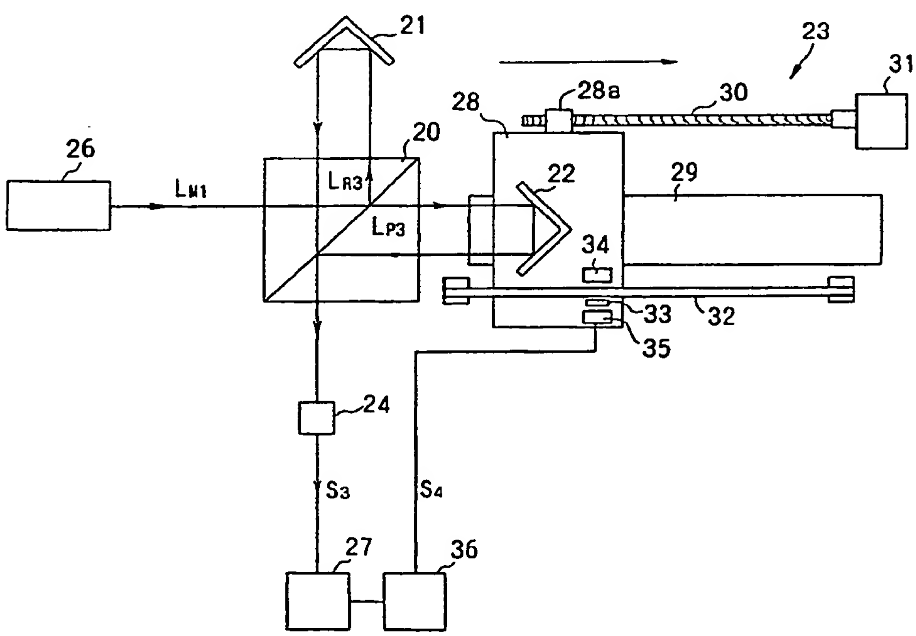

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FIG. 1

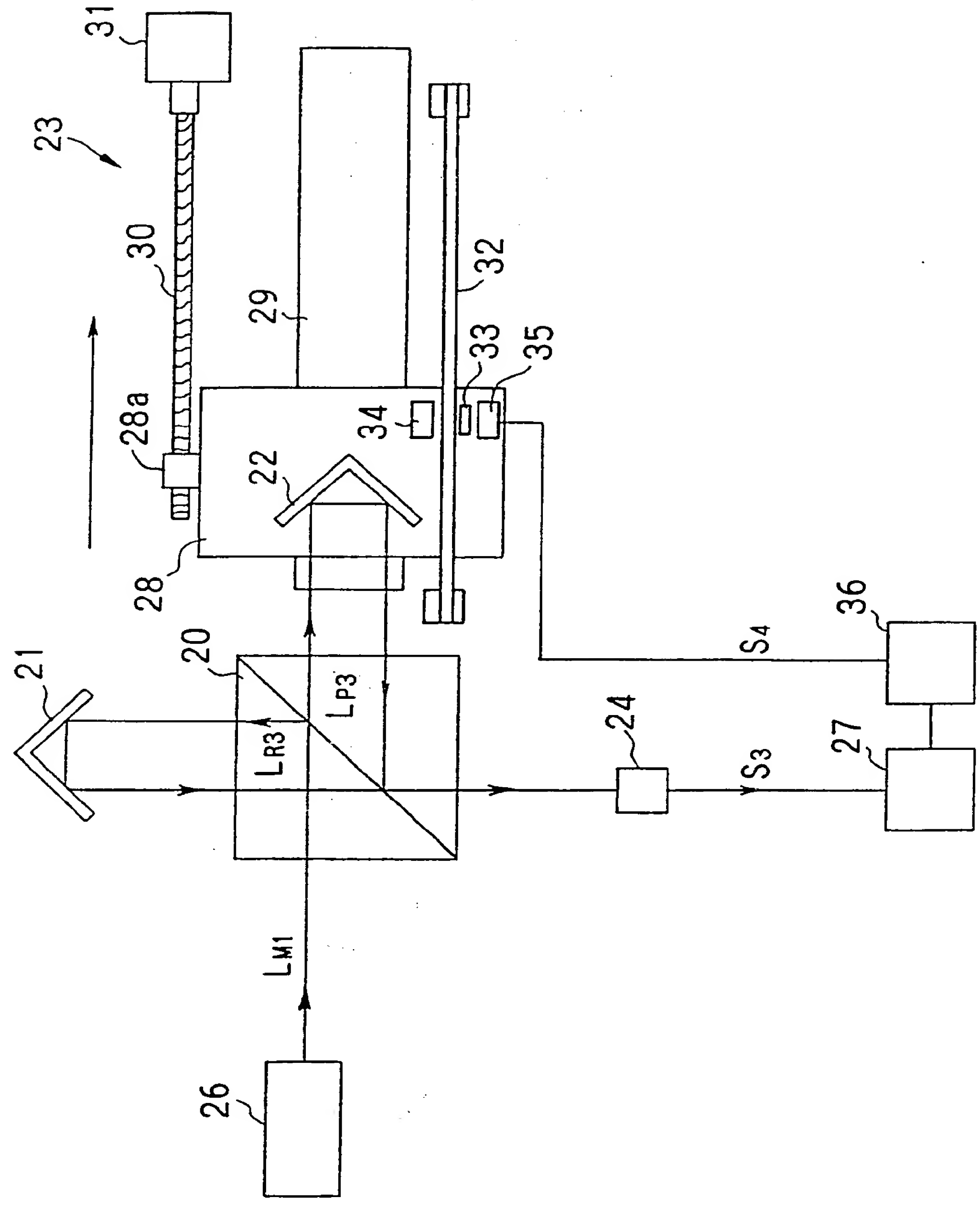


FIG. 2

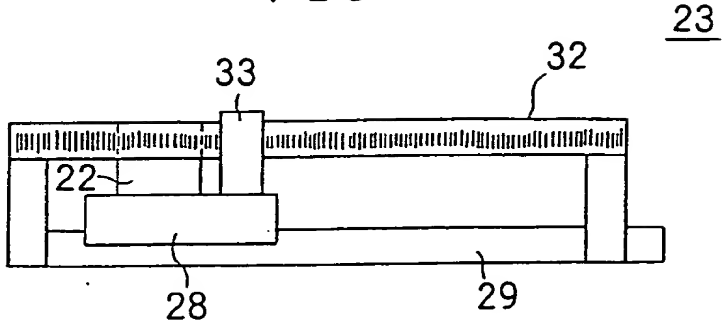


FIG. 3

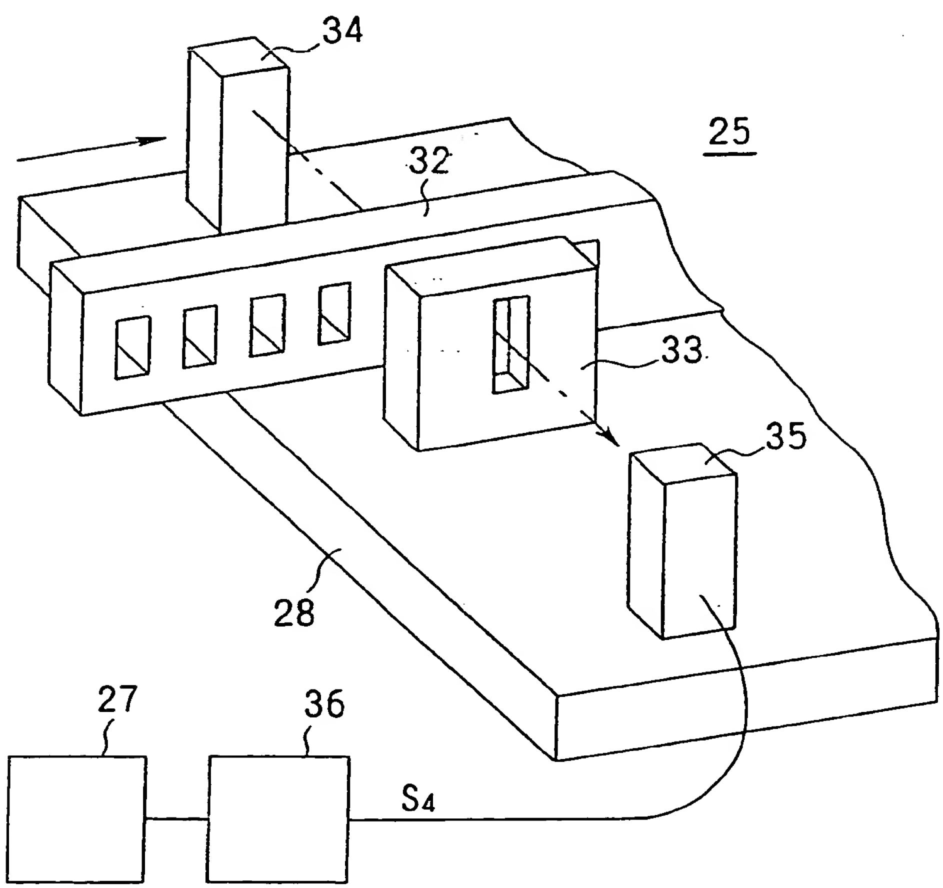


FIG. 4

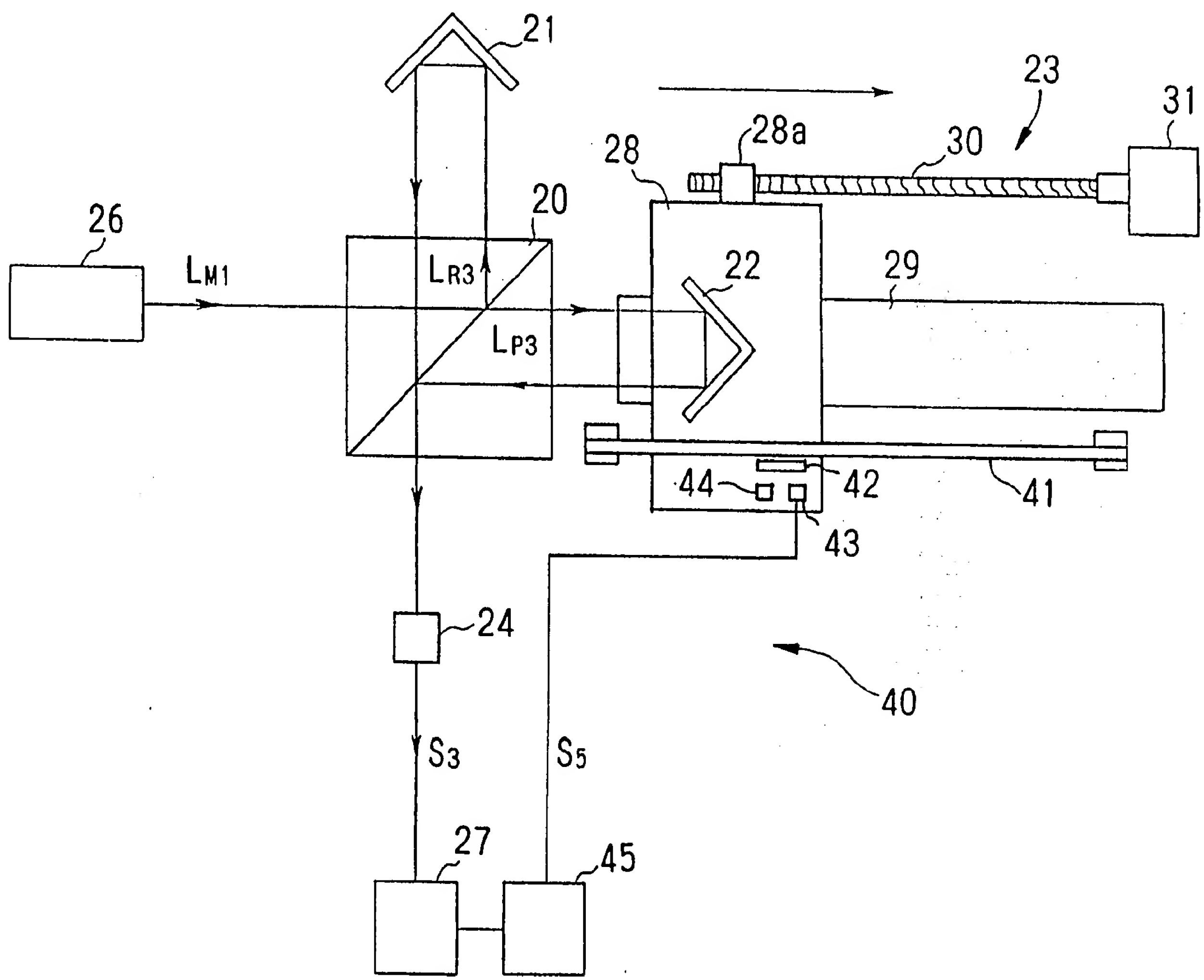

21
23
31
28a
30
28
20
26
L_{M1}
L_{R3}
22
29
L_{P3}
44
42
41
43
24
40
S_3
S_5
27
45

FIG. 5

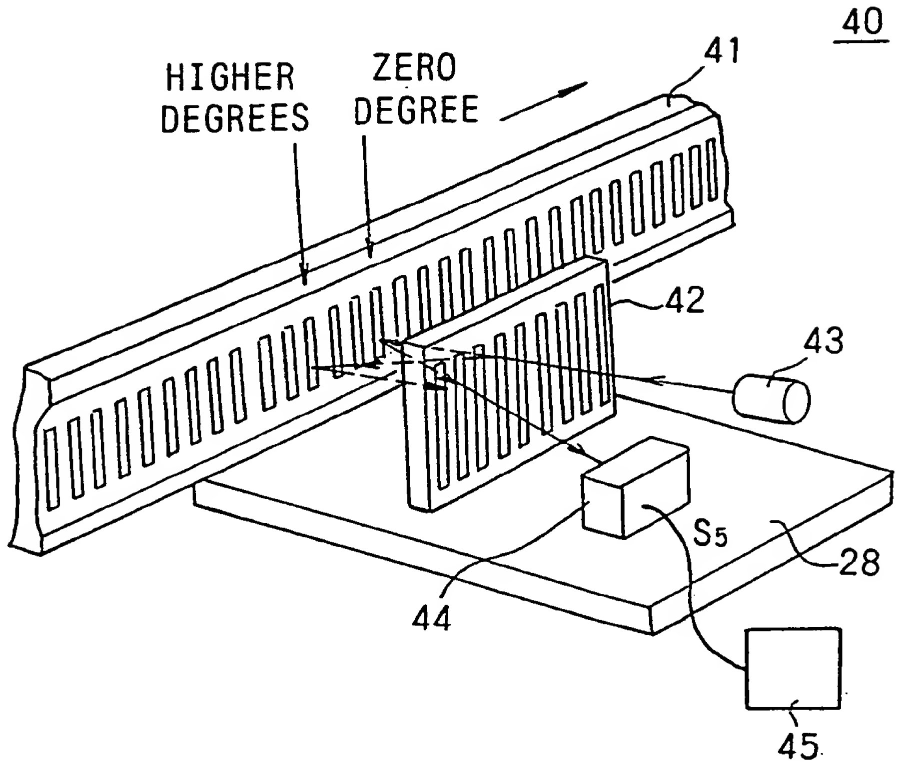


FIG. 7 PRIOR ART

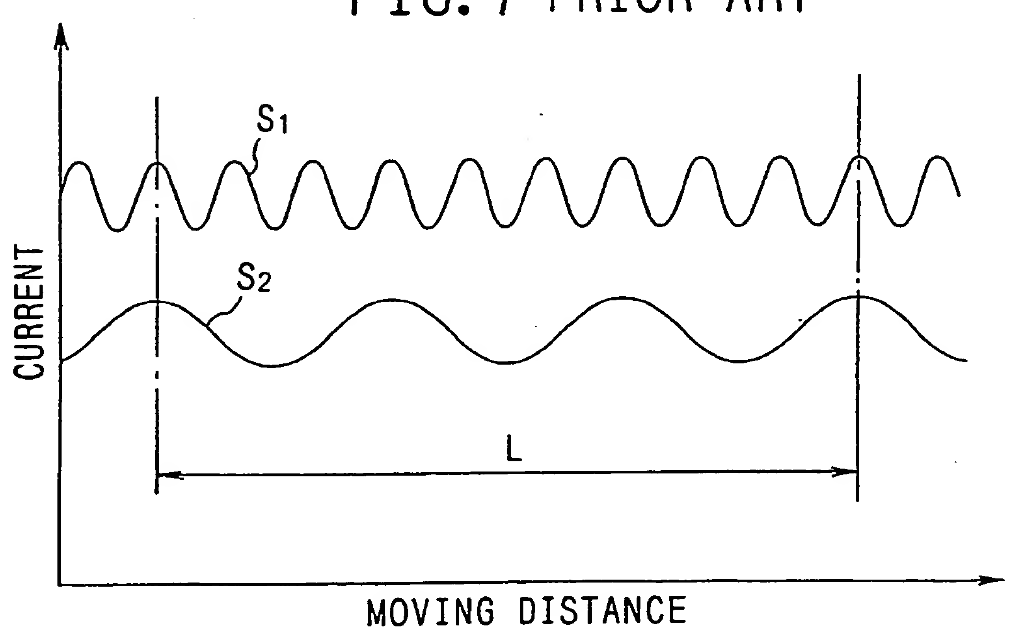
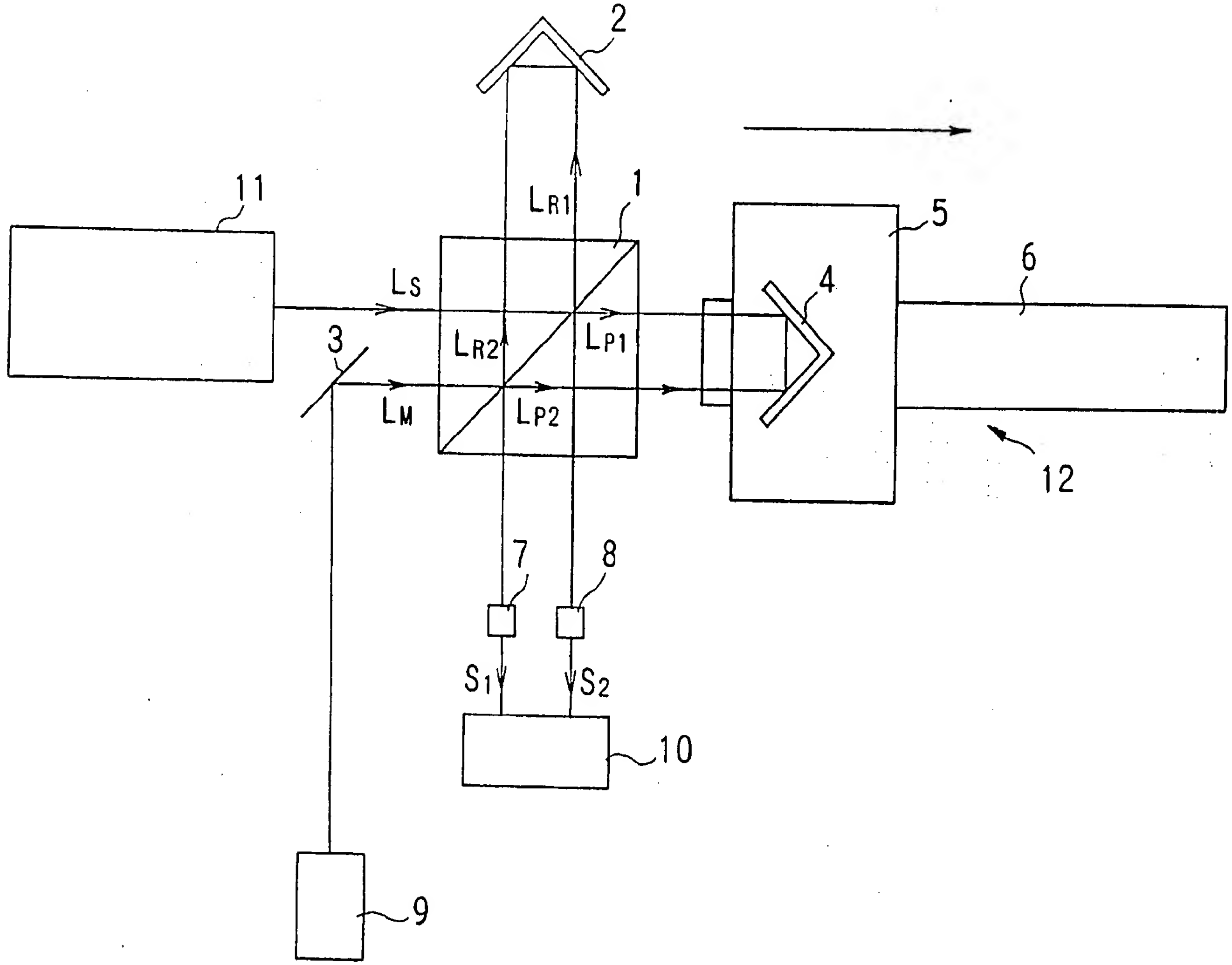


FIG. 6 PRIOR ART



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Optical Wavemeter

Background of the Invention

Field of the Invention

The present invention relates to optical wavemeters, and more particularly, to optical wavemeters which measure the wavelength of light to be measured using an interferometer.

Background Art

An example of the structure of a conventional optical wavemeter will be explained with reference to Fig. 6. In Fig. 6, a beam splitter 1, fixed mirrors 2 and 3, a moving mirror 4, a moving stage 5, a guide rail 6, light receivers 7 and 8, a light source 9, a wavelength calculator 10, and a reference light source 11, are provided. The moving mirror 4 is fixed on the moving stage 5. The moving stage 5 and the guide rail 6 form a linear moving mechanism 12 which moves the moving mirror 4 in parallel with the direction of an optical axis of light injected into the moving mirror 4. The wavelength of light emitted from the light source 9 is to be measured.

A reference light L_S with known wavelength from the reference light source 11 is divided into a reflected light L_{R1} and a passing light L_{P1} by the beam splitter 1. The reflected light L_{R1} is reflected by the fixed mirror 2, passing through the beam splitter 1, and is then received by the light receiver 7. The passing light L_{P1} is reflected by the moving mirror 4 and the beam splitter 1, and is then received by the light receiver 7.

When the reflected light L_{R1} and the passing light L_{P1} are received by the light receiver 7, since the reflected light L_{R1} and the passing light L_{P1} interfere with each other in the light receiver 7, an electric signal S_1 in response to the intensity of an interference light is supplied from the light receiver 7 to the wavelength calculator 10.

A light L_M of unknown wavelength to be measured from the light source 9 is reflected by the fixed mirror 3, being divided into a reflected light L_{R2} and a passing light L_{P2} by the beam splitter 1. The reflected light L_{R2} is reflected by the fixed mirror 2, passing through the beam splitter 1, and is then received by the light receiver 8. The passing light L_{P2} is reflected by the moving mirror 4 and the beam splitter 1, and is then received by the light receiver 8. When the reflected light L_{R2} and the passing light L_{P2} are received by the light receiver 8, since the reflected light L_{R2} and the passing light L_{P2} interfere with each other in the light receiver 8, an electric signal S_2 in response to the intensity of an interference light is supplied from the light receiver 8 to the wavelength calculator 10.

When the moving stage 5 moves on the guide rail 6 in linear motion in the direction shown by an arrow in Fig. 6, the moving mirror 4 moves based on the motion of the moving stage 5, and the electric signals S_1 and S_2 vary in response to periodic variation of the intensity of the interference lights caused by the motion of the moving mirror 4. Since each wavelength of the electric signals S_1 and S_2 corresponds to each wavelength of the reference light L_S and the light L_M, respectively, when the moving distance of the linear moving mechanism 12 is optionally set, the

wavenumber of the electric signals S_1 and S_2 are calculated in the wavelength calculator 10, and then the wavelength of the light L_M can be obtained based on formulas (1) and (2).

$$L=\lambda 1*k=n*\lambda 2 \qquad (1)$$

$$\lambda 1=n*\lambda 2/k \qquad (2)$$

In formulas (1) and (2), L represents an optionally set moving distance, $\lambda 1$ and $\lambda 2$ represent the wavelengths of the light L_M and the reference light L_S, and n and k represent the wavenumber of the electric signals S_1 and S_2. Fig. 7 shows an example of the waveforms of the electric signals S_1 and S_2. In Fig. 7, a vertical axis indicates a current and a horizontal axis indicates the moving distance of the moving stage 5. As shown by Fig. 7, the current of the electric signals S_1 and S_2 vary in response to the moving distance L of the moving mechanism 12.

In the above-mentioned conventional optical wavemeter, in order to accurately measure the wavelength of a light to be measured, the reference light source 11 emitting the reference light L_S with known wavelength must be used. However, since the length of a resonator in the present reference light source 11 is long, there is a drawback in that the overall apparatus is large. Moreover, in the above-mentioned conventional optical wavemeter, since both the reference light L_S and the light L_M are injected into the beam splitter 1, the adjustment of the optical axis is complex. In addition, since the diameter of the resonator in the reference light source 11 is also large, when both the reference light L_S and the light L_M are injected in the beam splitter 1, the optical path of the reference light L_S or the light L_M must be changed using the fixed mirror 3 and the like to inject it into the beam splitter 1. Accordingly, the adjustment of the

optical axis is further complicated.

Summary of the Invention

In consideration of the above problems, it is an object of the present invention to provide an optical wavemeter which is able to easily adjust an optical axis of a light of unknown wavelength to be measured and which is of compact construction without a reference light source or a fixed mirror for changing the optical path.

To satisfy this object, the present invention provides an optical wavemeter comprising: a beam splitter for dividing a light having a wavelength to be measured into a first light and a second light; a fixed mirror for reflecting the first light so as to inject it back into the beam splitter; a moving mirror for reflecting the second light so as to inject it back into the beam splitter; a linear moving mechanism having a moving stage on which the moving mirror is secured and for moving the moving mirror in parallel with the direction of an optical axis of light injected into the moving mirror; a light receiver for transforming an interference light generated by the synthesis of a light via the beam splitter and the fixed mirror and a light via the beam splitter and the moving mirror into an electric signal; a length measuring machine for detecting the moving distance of the moving stage; and a wavelength calculator for calculating the wavelength of the light to be measured based on the wavenumber of the electric signal and the moving distance.

According to the present invention, a positive effect is that an optical wavemeter can easily adjust an optical axis of a

light of unknown wavelength to be measured and can be of compact construction without a reference light source or a fixed mirror for changing an optical path.

Brief Explanation of the Drawings

Fig. 1 shows a plan view of the structure of an optical wavemeter based on a first preferred embodiment of the present invention.

Fig. 2 shows a side view of the structure of an linear moving mechanism 23 shown in Fig. 1.

Fig. 3 shows a partial oblique view of the structure of a length measuring machine 25.

Fig. 4 shows a plan view of the structure of an optical wavemeter based on a second preferred embodiment of the present invention.

Fig. 5 shows a partial magnified oblique view of the structure of a length measuring machine 40.

Fig. 6 shows a plan view of the structure of a conventional optical wavemeter.

Fig. 7 shows an example of the waveforms of the electric signals S_1 and S_2.

Detailed Description of the Preferred Embodiment

Hereinafter, a first preferred embodiment of the present

invention will be explained with reference to Figs. 1 through 3. Fig. 1 shows a plan view of the structure of an optical wavemeter based on the first preferred embodiment of the present invention. Fig. 2 shows a side view of the structure of an linear moving mechanism 23 shown in Fig. 1. In Figs. 1 and 2, a beam splitter 20, a fixed mirror 21, a moving mirror 22, a linear moving mechanism 23, a light receiver 24, a length measuring machine 25, a light source 26, and a wavelength calculator 27, are provided. The linear moving mechanism 23 which moves the moving mirror 22 in parallel with the direction of an optical axis of light with wavelength to be measured, consists of a moving stage 28, a guide rail 29, a ball screw mechanism 30, and a motor 31. The moving mirror 22 is fixed on the moving stage 28. One end of the ball screw mechanism 30 is fixed to a shaft of the motor 31. The other end of the ball screw mechanism 30 is engaged with a projection portion 28_a projected from a left side of the moving stage 28 by means of a thread formed around ball screw mechanism 30 and a threaded hole formed in the projection portion 28_a. Therefore, when the motor 31 turns, the ball screw mechanism 30 transforms rotary motion of the motor 31 into linear motion of the moving stage 28. The wavelength of the light source 26 is to be measured.

Fig. 3 shows a partial magnified oblique view of the structure of the length measuring machine 25. In Figs. 1 through 3, the length measuring machine 25 consists of a fixed glass grating 32, a moving glass grating 33, a light source 34, a light receiver 35, and a distance calculator 36. In Fig. 3, the light source 34 is secured on the moving stage 28 so that an optical axis (see the chained line arrow shown in Fig. 3) of a light

emitted therefrom is vertically to the moving direction of the moving stage 28. The moving glass grating 33 and the light receiver 35 are vertically secured to the optical axis of the light emitted from the light source 34 on the moving stage 28. Furthermore, the fixed glass grating 32 is vertically arranged to the optical axis of the light emitted from the light source 34 between the moving glass grating 33 and the light source 34 above the moving stage 28. A plurality of slits are formed at the required pitch along the longitudinal direction in the fixed glass grating 32. The moving glass grating 33 has a slit of the required size.

A light L_{M1} of unknown wavelength to be measured from the light source 26 is divided into a reflected light L_{R3} and a passing light L_{P3} by the beam splitter 20. The reflected light L_{R3} is reflected by the fixed mirror 21, passing through the beam splitter 20, and is then received by the light receiver 24. The passing light L_{P3} is reflected by the moving mirror 22 and the beam splitter 20, and is then received by the light receiver 24. When the reflected light L_{R3} and the passing light L_{P3} are received by the light receiver 24, since the reflected light L_{R3} and the passing light L_{P3} interfere with each other in the light receiver 24, an electric signal S_3 in response to the intensity of an interference light is supplied from the light receiver 24 to the wavelength calculator 27.

When the moving stage 28 moves on the guide rail 29 in linear motion toward the direction shown by an arrow in Fig. 1 by the rotation of the ball screw mechanism 30 using the motor 31, the moving mirror 22 moving based on the motion of the moving stage 28, the electric signal S_3 varies in response to the

periodic variation of the intensity of the interference light caused by the motion of the moving mirror 22. The wavelength of the electric signal S_3 corresponds to the wavelength of the light L_{M1}.

In Fig. 3, the light emitted from the light source 34 passes through the slit among the slits in the fixed glass grating 32 and the slit in the moving glass grating 33, and is then received by the light receiver 35. When the moving stage 28 moves toward the direction shown by the arrow in Fig. 3, the period of the electric signal S_4 from the light receiver 35 corresponds to a pitch of the fixed glass grating 32. The distance calculator 36 calculates the moving distance L of the moving stage 28 based on the counted value of the wavenumber of the electric signal S_4 and the distance between the adjacent slits in the fixed glass grating 32, and supplies the calculated result to the wavelength calculator 27. The wavelength calculator 27 calculates the wavelength of the light L_{M1} based on the counted value of the wavenumber k of the electric signal S_3 and the moving distance L supplied from the distance calculator 35 using formula (3).

$$\lambda 1 = L/k \qquad (3)$$

In the formula (3), L represents the moving distance of the linear moving mechanism 23, $\lambda 1$ represents the wavelength of the light L_{M1}, and k represents the wavenumber of the electric signal S_3.

Next, a second preferred embodiment of the present invention will be explained with reference to Figs. 4 and 5. Fig. 4 shows a plan view of the structure of an optical wavemeter based on the second preferred embodiment of the present invention. Fig. 5 shows a partial magnified oblique view of the structure of the

length measuring machine 40 shown in Fig. 4. In Figs. 4 and 5, structures in this second embodiment that are the same as structures in the first embodiment shown in Figs. 1 through 3 have the same numbers, and their explanations are not repeated. In Figs. 4 and 5, the length measuring machine 40 consists of a fixed glass grating 41, a moving glass grating 42, a light source 43, a light receiver 44, and a distance calculator 45. In Fig. 5, the light source 43 is secured on the moving stage 28 so that an optical axis of a light emitted therefrom is vertical to the moving direction of the moving stage 28. The moving glass grating 42 is vertically secured to the optical axis of the light emitted from the light source 43 on the moving stage 28. Furthermore, the fixed glass grating 41 is vertically arranged with respect to the optical axis of the light emitted from the light source 43 beyond the moving glass grating 42 above the moving stage 28. A plurality of stripes made up of opaque material are placed at the required pitch along the longitudinal direction on the fixed glass grating 41 and the moving glass grating 42. The area without the stripes on the surface of the fixed glass grating 41 can reflect the light. The area without the stripes on the surface of the moving glass grating 42 allows light to pass therethrough.

A light L_{M1} of unknown wavelength to be measured from the light source 26 is divided into a reflected light L_{R3} and a passing light L_{P3} by the beam splitter 20. The reflected light L_{R3} is reflected by the fixed mirror 21, passing through the beam splitter 20, and is then received by the light receiver 24. The passing light L_{P3} is reflected by the moving mirror 22 and the beam splitter 20, and is then received by the light receiver 24.

When the reflected light L_{R3} and the passing light L_{P3} are received by the light receiver 24, since the reflected light L_{R3} and the passing light L_{P3} interfere with each other in the light receiver 24, an electric signal S_3 in response to the intensity of an interference light is supplied from the light receiver 24 to the wavelength calculator 27.

When the moving stage 28 moves on the guide rail 29 in linear motion shown by an arrow in Fig. 4 by the rotation of the ball screw mechanism 30 using the motor 31, the moving mirror 22 moving based on the motion of the moving stage 28, the electric signal S_3 varies in response to the periodic variation of the intensity of the interference light caused by the motion of the moving mirror 22. The wavelength of the electric signal S_3 corresponds to the wavelength of the light L_{M1}.

In Fig. 5, just when the light emitted from the light source 43 passes through the moving glass grating 42 made up of transparent material, the light is diffracted by the moving glass grating 42 and thereby lights of zero and higher degrees in the diffraction degree thereof are generated. Next, the diffracted lights of zero and higher degrees are reflected and diffracted by the fixed glass grating 41 made up of reflective material, again passing through and being diffracted by the moving glass grating 42, and then are received by the light receiver 44. When the moving stage 28 moves toward the direction shown by the arrow in Fig. 5, the phase of the light of higher degrees varies, but the phase of the light of zero degree does not vary. Therefore, an electric signal S_5 with sine waveform corresponding to the phase difference between the lights of zero and higher degrees is output from the light receiver 44. The distance calculator 45

calculates the moving distance L of the moving stage 28 based on the counted value of the wavenumber of the electric signal S_5 and the wavelength of the light emitted from the light source 43 and supplies the calculated result to the wavelength calculator 27. The wavelength calculator 27 calculates the unknown wavelength of the light L_{M1} based on the counted value of the wavenumber k of the electric signal S_3 and the moving distance L supplied from the distance calculator 45 using the above-mentioned formula (3).

What is claimed is:

1. An optical wavemeter comprising:

a beam splitter for dividing a light having wavelength to be measured into a first light and a second light;

a fixed mirror for reflecting said first light so as to inject it back into said beam splitter;

a moving mirror for reflecting said second light so as to inject it back into said beam splitter;

a linear moving mechanism having a moving stage on which said moving mirror is secured and for moving said moving mirror in parallel with the direction of an optical axis of light injected into said moving mirror;

a light receiver for transforming an interference light generated by the synthesis of a light via said beam splitter and said fixed mirror and a light via said beam splitter and said moving mirror into an electric signal;

a length measuring machine for detecting the moving distance of said moving stage; and

a wavelength calculator for calculating the wavelength of said light to be measured based on the wavenumber of said electric signal and said moving distance.

2. An optical wavemeter according to claim 1, wherein said length measuring machine comprising:

a light source being secured on said moving stage so that an optical axis of a light therefrom is vertical to the moving direction of said moving stage;

a moving glass grating being vertically secured to said

optical axis on said moving stage, into which said light is injected;

a fixed glass grating being vertically arranged to said optical axis between said light source and said moving glass grating above said moving stage, of which a plurality of glass gratings are vertically arranged with respect to said moving direction with the required pitch on the surface thereof;

a light receiver for receiving a light through said fixed glass grating and said moving glass grating from said light source and delivering an electric signal in response to the movement of said moving stage; and

a distance calculator for calculating a moving distance of said moving stage based on the wavenumber of said electric signal.

3. An optical wavemeter according to claim 1, wherein said length measuring machine comprising:

a light source being secured on said moving stage so that an optical axis of a light therefrom is vertical to the moving direction of said moving stage;

a fixed glass grating being vertically arranged with respect to said optical axis above said moving stage, of which a plurality of glass gratings are vertically arranged to said moving direction with the required pitch on the surface thereof;

a moving glass grating being vertically secured to said optical axis between said light source and said fixed glass grating on said moving stage, into which said light is injected;

a light receiver for receiving a light emitted from said light source and diffracted by said fixed glass grating and said

moving glass grating and delivering an electric signal in response to the movement of said moving stage; and

a distance calculator for calculating moving distance of said moving stage based on the wavenumber of said electric signal.

4. An optical wavemeter comprising:

a beam splitter for dividing a light beam having wavelength to be measured into a first light beam and a second light beam;

a fixed mirror for reflecting said first light beam so as to inject it back into said beam splitter;

a moveable mirror for reflecting said second light so as to inject it back into said beam splitter;

a linear moving mechanism having a movable stage on which said moveable mirror is secured and for moving said moveable mirror in parallel with the direction of an optical axis of light injected into said movable mirror;

a light receiver for transforming an interference light beam generated by the synthesis of a light beam via said beam splitter and said fixed mirror and a light beam via said beam splitter and said moveable mirror into an electric signal;

a length measuring machine for detecting a distance of movement of said moving stage; and

a wavelength calculator for calculating the wavelength of said lightbeam to be measured based on the wavenumber of said electric signal and said distance of movement.

5. An optical wavemeter according to claim 4, wherein said length measuring machine comprises:

a light source being secured on said moveable stage so that an optical axis of a light beam therefrom is vertical to direction of movement of said moveable stage;

a moveable grating being vertically secured to said optical axis on said moveable stage, into which said light beam is injected;

a fixed grating being vertically arranged to said optical axis between said light source and said moveable grating above said moveable stage, of which a plurality of gratings are vertically arranged with respect to the direction of movement with the required pitch on the surface thereof;

a light receiver for receiving a light beam through said fixed grating and said moveable grating from said light source and delivering an electric signal in response to the movement of said moveable stage; and

a distance calculator for calculating a distance of movement of said moving stage based on the wavenumber of said electric signal.

6. An optical wavemeter according to claim 4, wherein said length measuring machine comprises:

a light source being secured on said moveable stage so that an optical axis of a light beam therefrom is vertical to the direction of movement of said moveable stage;

a fixed grating being vertically arranged with respect to said optical axis above said

moveable stage, of which a plurality of gratings are vertically arranged to the direction of movement with the required pitch on the surface thereof;

a moveable grating being vertically secured to said optical axis between said light source and said fixed grating on said moveable stage, into which said light is injected;

a light receiver for receiving a light beam emitted from said light source and diffracted by said fixed grating and said moveable grating and delivering an electric signal in response to the movement of said moveable stage; and

a distance calculator for calculating distance of movement of said moveable stage based on the wavenumber of said electric signal.

7. An optical wavemeter comprising:

a beam splitter for dividing a light beam having a wavelength to be determined into a first light beam and a second light beam,

optical means for passing the first light beam through a path of predetermined distance,

a mirror movable with respect to the beam splitter to enable variation in the distance of the optical path of the second beam,

means for determining the distance of movement of the movable mirror in use,

means for combining both the first and second beams to enable an interference pattern to be detected by a detector which generates a signal representative of the interference pattern, and

a wavelength calculator which operably calculates the wavelength of the light beam based on the detector signal and the distance of movement of the movable mirror.

8. An optical wavemeter according to claim 7 wherein the optical means comprises a mirror of fixed separation from the beam splitter.

9. An optical wavemeter according to claim 7 or 8 wherein the combining means consists of the beam splitter.

10. An optical wavemeter according to any one of claims 7 to 9 wherein the movable mirror is mounted on a movable stage.

11. An optical wavemeter according to claim 10 wherein the movable stage is operably driven by a motor to cause movement thereof.

12. An optical wavemeter according to any one of claims 7 to 11 wherein the distance determining means comprises a light source associated with the movable mirror, a first grating having a fixed position relative to the light source, a movable grating, a light receiver for receiving a light beam having been refracted by the fixed and movable gratings which receiver operably produces a signal representative of the movement of the movable mirror, and a distance calculator for calculating the distance of movement of the movable mirror based on the signal from the light receiver.

13. An optical wavemeter according to claim 12 wherein the light beam from the light source passes through the fixed grating prior to passing through the movable grating and into the light receiver.

14. An optical wavemeter according to claim 12 wherein the light beam from the light source passes through the movable grating prior to being refracted by said fixed grating.

15. An optical wavemeter according to claim 14 wherein the light beam refracted by the fixed grating passes through the movable grating prior to being detected by the light receiver.

16. An optical wavemeter according to claim 14 or 15 wherein the fixed grating comprises a mirror having a series of non-reflecting strips.

17. An optical wavemeter substantially as described herein with reference to and as shown in Figures 1 to 3.

18. An optical wavemeter substantially as described herein with reference to and as shown in Figures 4 and 5.

19. A device for determining the distance of movement of a moveable mirror in an optical wavemeter comprising a light source associated with the movable mirror, a first grating having a fixed position relative to the light source, a movable grating, a light receiver for

receiving a light beam having been refracted by the fixed and movable gratings which receiver operably produces a signal representative of the movement of the movable mirror, and a distance calculator for calculating the distance of movement of the movable mirror based on the signal from the light receiver.

20. A device according to claim 19 wherein the light beam from the light source passes through the fixed grating prior to passing through the movable grating and into the light receiver.

21. A device according to claim 19 wherein the light beam from the light source passes through the movable grating prior to being refracted by said fixed grating, and/or wherein the light beam refracted by the fixed grating passes through the moveable grating prior to being detected by the light receiver, and/or wherein the fixed grating comprises a mirror having a series of non-reflecting strips.

22. A device for measuring the distance of movement of a moveable mirror in an optical meter substantially as described herein with reference to and as shown in Figures 1 to 3.

23. A device for measuring the distance of movement of a moveable mirror in an optical meter substantially as described herein with reference to and as shown in Figures 4 and 5.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report) 20	Application number GB 9412891.5
Relevant Technical Fields (i) UK Cl (Ed.M) G1A (AHSL, AHX) (ii) Int Cl (Ed.5) G01J 9/02	Search Examiner H J EDWARDS Date of completion of Search 26 SEPTEMBER 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI, EDOC	Documents considered relevant following a search in respect of Claims :- 1 TO 18

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E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 1195839	(BARRINGER) Figure 1	1, 4, 7-11
X	EP 0478785 A1	(ANRITSU) whole document	1, 4, 7-11
X	EP 0436752	(ADVANTEST) whole document	1, 4, 7-11
X	EP 0332699 A1	(KOMATSU) Figure 7	1, 4, 7-11
X	EP 0256300 A2	(PERKIN-ELMER) Figures 5, 6, 7	1, 4, 7-11
X	US 4426155	(MONCHALIN) whole document	1, 4, 7-11
X	US 4319843	(GORNALL) whole document	1, 4, 7-11
X	US 4165183	(HALL) whole document	1, 4, 7-11

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